FERMILAB-PUB-75-135-E

Interpretation of Inelastic Hadron-Nucleus Collisions

H.Fukushima and G.Fujioka

Department of Physics, Kobe University, Kobe

1 Introduction

In the interaction of high energy ($\gtrsim 100$ GeV) hadron with a nucleus, there are several interesting points[1] which are not fully explained by the existing models[2]. Firstly, the cross section does not obey the simple $A^{2/3}$-rule. Increase of multiplicities with A is rather slower than expected. Some models are proposed to explain this point.Angular distributions are also to be explained.

Here we propose two models which seem to explain various experimental results fairly well. The cross section does not depend on the type of intra-nuclear interactions.

2 Mass number dependence of inelastic cross sections

The target nucleus can be considered as a sphere of radius $r_0 A^{1/3}$, where r_0 is the Compton wave length of pion and A is the mass number of the target. Let X be the number of nucleons which can interact with the incident hadron and $\pi r_0^2 W(X,A)$ the X-distribution for the nucleus with mass number A.

When the incident hadron comes in a region near a nucleon it is assumed to interact with a probability c. Then the probability that the incident hadron interacts with the i-th particle of X nucleons is given as

$$P(i) = (1-c)^{i-1} \cdot c \ .$$

Thus the probability that the incident hadron interacts in a target nucleus for a certain value of X is

$$\sum_{i=1}^{X} P(i) = 1-(1-c)^X .$$

The total cross section $\sigma_{tot}(A)$ is calculated as follows,

$$\sigma_{tot}(A) = \pi r_0^2 \sum_X (1-(1-c)^X) W(X,A) \ .$$

Assuming this consideration applicable for a nucleon (A=1),

$$\sigma_{tot}(1) = \pi r_0^2 \frac{2}{3} c \ .$$

When we take the value of c as 1 for incident nucleon and as 0.6 for incident pion, $\sigma_{tot}(1)$ is consistent with the experimental values for 100 GeV region. σ_{tot}'s for p-N and π-N interactions calculated with these c-values are shown in Fig. 1 as functions of A.

The interaction considered here is the type in which it is clearly identified as inelastic in, e.g., nuclear emulsion experiments by multiple production or emission of heavily ionizing tracks. Therfore, we should subtract elastic and nearly elastic cross sections. This cross section $\sigma_s(A)$ can be considered as follows,

$$\sigma_s(A) = \pi r_0^2 k W(1.A) \quad ,$$

because, if $X \geqq 2$, the scattered particles will cause the next interaction inside the target nucleus even when the first one is nearly elastic and the interaction shows inelastic feature. Putting k=0.17, $\sigma_s(1)$ coincides with σ_{el} for 200 GeV p-p interactions.

The inelastic cross section $\sigma_{in}(A)$ thus calculated is shown in Fig. 2 with experimental values. The expected cross section can be approximated by $A^{0.77}$, not by $A^{2/3}$, and agrees fairly well with experimental data.

3 Interactions inside the target nucleus

To obtain the multiplicity and angular distributions of the hadron-nucleus collisions, secondary interactions inside the nucleus should be taken into consideration. As the model for these intra-nuclear interaction, we consider two extreme cases.

(1) Created particles can be considered as independent and the whole interactions are the superposition of these individual interactions.

(2) Created particles are not independent before emerging the nucleus, and the secondary interactions are those between this group (may be called excited state or fireball) and the next target nucleon.

3-1 Independent reaction model

Secondary particles from the first interactions have mainly transverse momenta less than, say, 1 GeV/c, and particles with energy ($\gtrsim 5$ GeV) enough to contribute secondary multiple productions are emitted in the angle less than 0.2 rad. This means that these particles do not diverge more than the order of magnitude of r_0, and the secondary multiplications take place with nucleons forming a line. Therfore, the number of these interactions, including the first one, hardly exceeds six even for the largest nucleus when the impact parameter is zero.

To obtain results, we must assume the energy of particles causing these secondary interactions. The average multiplicity as a function of A for average energy of $0.1E_0$ and $0.15E_0$ are shown in Fig. 3 with experimental data for 200 GeV p-nucleus collisions. The agreement is fairly well.

The number of heavily ionizing tracks can be considered to be proportional to the number of intra-nuclear interactions, and N_h is calculated to be quadratic form of X. Obtaining coefficients from 200 GeV p-p and p-nucleus interactions, $\langle n_s \rangle$ vs. N_h curves are shown in Fig. 4 for various energies. Experimental results are also shown in the figure.

The angular distribution for $N_h=0$(quasi-nucleon-nucleon collisions) is fairly well expressed by Gaussian function as shown in Fig.5. Fig.5.is expressed in probability paper and the linear shape means Gaussian. For medium and large N_h, the angular distribution subtracting that of $N_h=0$ are shown in Fig.6. These are also Gaussian corresponding to 0.1~0.15 times incident energy.

Thus this model explains experimental results fairly well.

3-2 Collective reaction model

Let j be the number of nucleons participating in the particle production, then the total energy in the j-th collision

$$E_j = E_0 + jM \cong E_0 ,$$

where M is the nucleon mass. Putting the projectile mass m,

$$S_j = (m^2 + j^2M^2 + 2jME_0) \cong 2jME_0 .$$

The Lorentz factor γ_j of the final state is expressed as

$$\gamma_j = (E_0 + jM)/\sqrt{S_j} \cong (E_0/2M)^{1/2} j^{1/2}$$

In this model, the incident hadron is considered to collide with a target of mass jM. But in this case the final volume V_j of interaction is not the same with V_1 of single collision.

Then we assume that the differential cross section is expressed as

$$d\sigma_n(1)/dy = f(n, \sqrt{s})g(y, \gamma_1)$$

for elementary interactions, and

$$d\sigma_{n'}(j)/dy = f(n, \sqrt{S_j}, V_1/V_j)g(y, \gamma_j) , \quad n' = nV_j/V_1 ,$$

for nucleus target.

Fitting V_j from 200 Gev p-N interactions, j is expressed by a linear function of X. The dependence of N_h on j is also determined from this experiment. The maximum of j is 8.4 for the largest nucleus.

The dependence of $\langle n_s \rangle$ on N_h is calculated for various primary energies, to compare with the first model. Though the assumptions are extremely different, the results do not differ so much as shown in Fig.7.

In conclusion, both models explain fairly well the various experimental results, and in the accuracy of the present experimental data it is difficult to decide which model is appropriate.

Ref.

1) T.Ogata:private communication.
Y.Konishi et al: preprint
A.Gurtu et al:Phys.Lett.50B 391,(1974)
Collaboration of Barcelona et al:Phys.Lett.48B 467(1974)
2) e.g.
K.Gottfried:CERN TH1735 (1973)

Figure Captions

Fig.1. Mass number dependence of p-nucleus and π-nucleus total cross sections calculated by this model.

Fig.2. Mass number dependence of p-nucleus total inelastic cross section calculated by this model.

Fig.3. Mass number dependence of average multiplicity of shower particles $\langle n_s \rangle$ calculated by independent reaction model,compaired with experimental data.

Fig.4. N_h-dependence of average multiplicity $\langle n_s \rangle$ obtained by independent reaction model and experimental values for different energies.

Fig.5. η distribution of shower particles for $N_h=0$,obtained from emulsion experiment. Expressed in the probability paper.

Fig.6. η distributions of shower particles obtained from emulsion experiment for (a) $1 \leq N_h \leq 8$ (b) $N_h \leq 9$, after subtraction of distribution for $N_h=0$ Expressed in the probability paper.

Fig.7. N_h-dependence of $\langle n_s \rangle$ calculated from collective reaction model.

Fig. 1

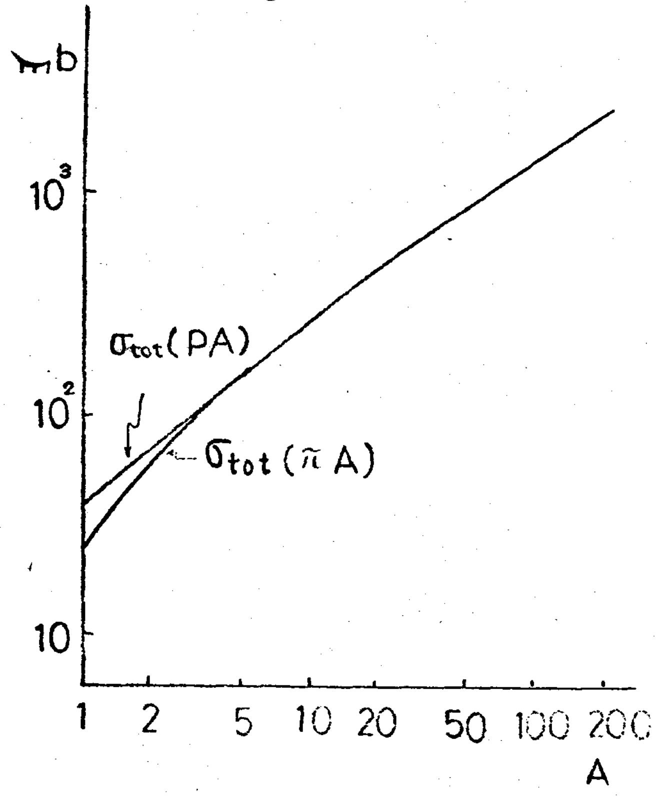

Fig. 2

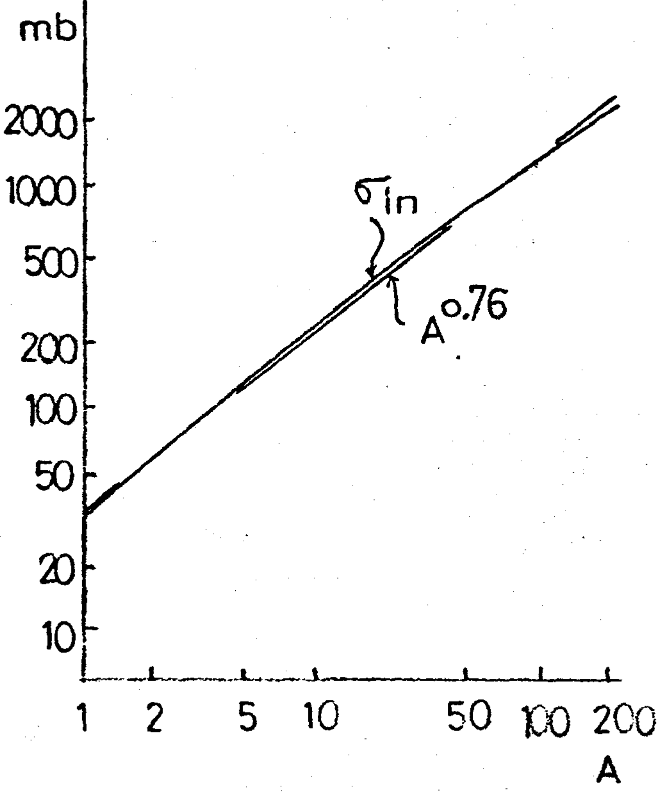

Fig. 3

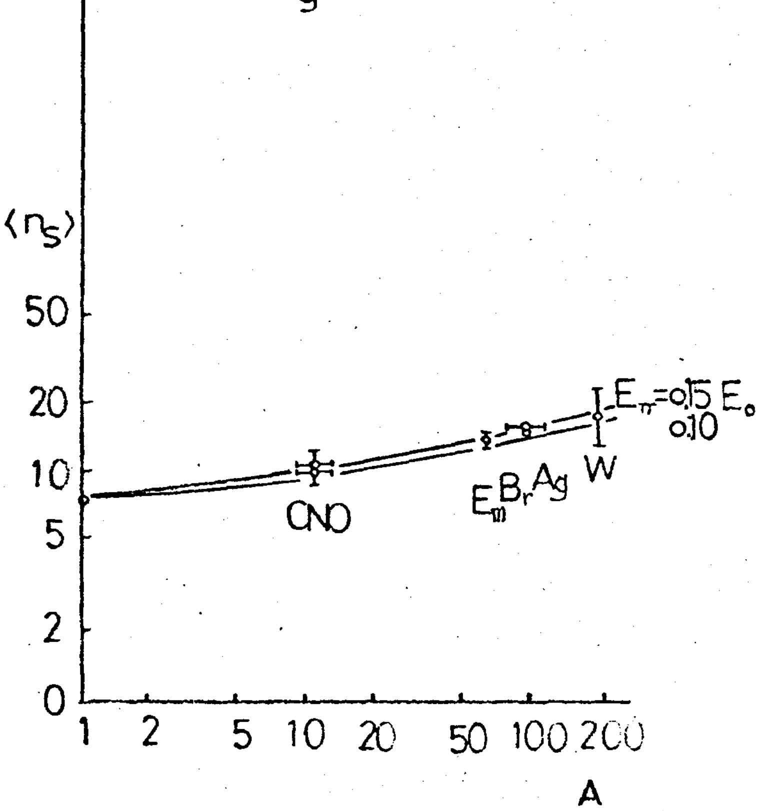

Fig. 4

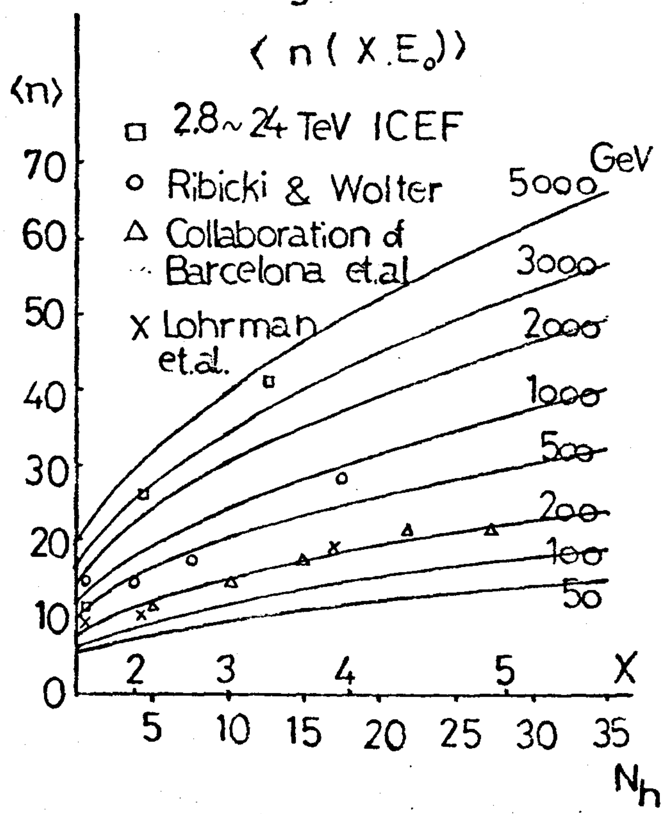

Fig. 5

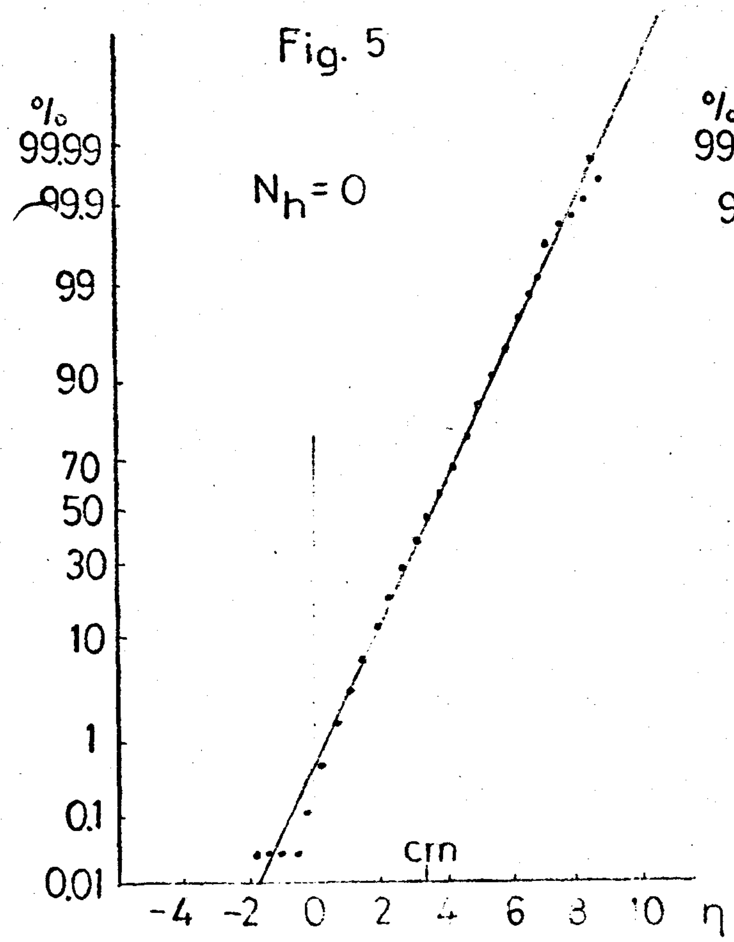

Fig. 6 a

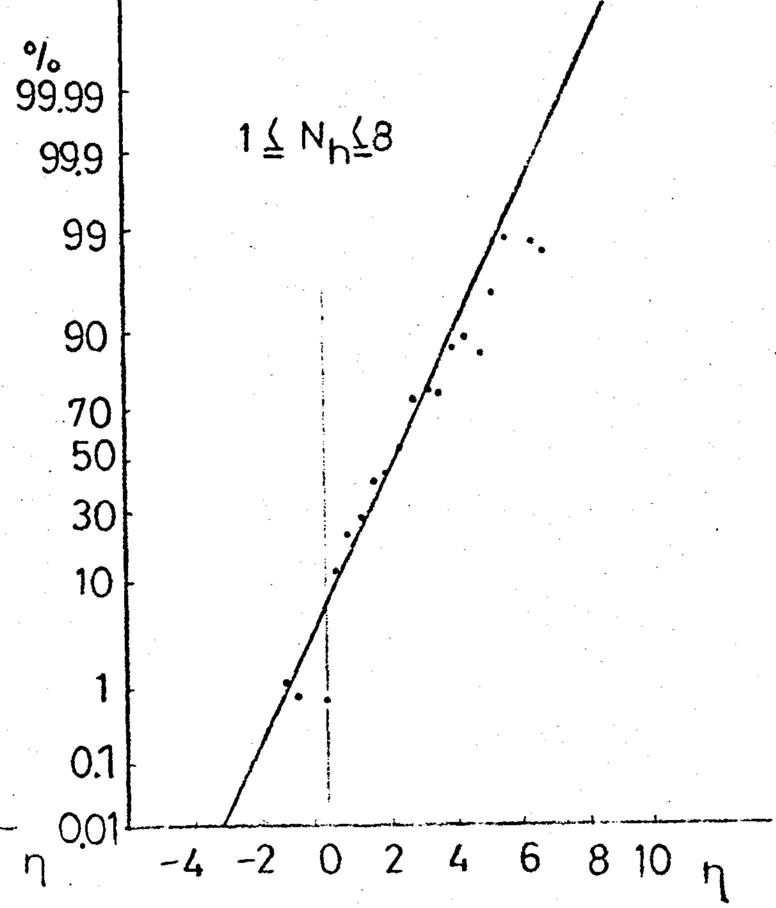

Fig. 6 b

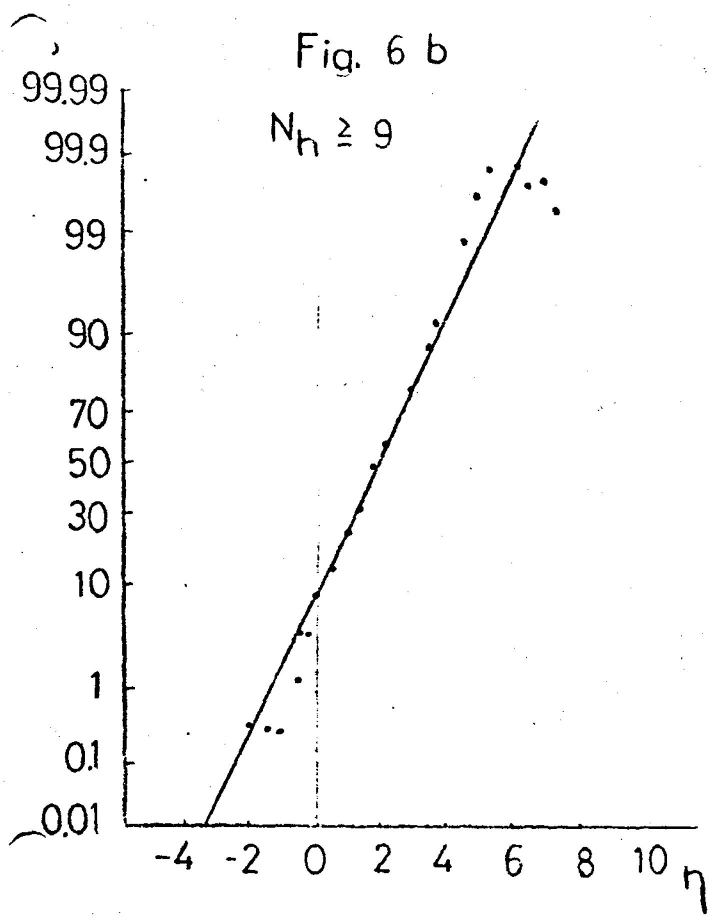

Fig. 7